Truro's Upper Pamet River: Environmental History and Future Prospects

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Abstract

The history of the Pamet River (Truro, Massachusetts) is presented as an example of how management of New England's coastal wetlands over nearly all of the past few centuries has focused primarily on short-term societal needs to the detriment of basic wetland functions and long-term social values. The development of the upper Pamet's salt marshes, over at least three millennia of post-glacial sea-level rise, was interrupted by diking and drainage in the late 19^{th}, and freshwater impoundment in the mid-20^{th} century. These hydrologic alterations have caused vegetation to shift from salt-tolerant grasses to salt-intolerant herbs, trees and shrubs, and have caused the wetland surface to subside well below the elevation of modern, undiked lower Pamet marshes. Major storms have overwashed the system's Atlantic barrier beach, temporarily flooding the subsided, and now freshwater, wetland with seawater. Consequent plant mortality and water quality problems have been averted only because recent overwashes have occurred during winter. It is suggested that land managers employ recent hydrologic, hydrographic and ecological research to work toward restoring the dynamic equilibrium between the Pamet wetlands and modern sea level, probably through the phased reintroduction of normal tidal flow from Cape Cod Bay. In this way, the upper Pamet's estuarine salt marsh, with all its attendant benefits to humans, may also be restored.

Introduction

Over the past several centuries, management of our coastal systems has been largely an *ad hoc* process: that is, major management decisions have been made to satisfy the current society's immediately perceived needs, with little regard for the perpetuation of a natural system's socially important ecological functions. For example, groins and jetties built along developed coasts worldwide to stop shoreline erosion have had the unintended result of disturbing littoral sediment budgets and increasing erosion rates downstream (Greiner & Lorenson 1976). Salt marsh diking, drainage and filling to control pest insect breeding have eliminated habitat for many commercially and ecologically important estuarine animals, (Neely 1958, Portnoy et al. 1987), caused water quality problems (Breemen 1982; Soukup & Portnoy 1986; Portnoy 1991, Anisfeld & Benoit 1997) and sometimes even favored pest insect production (Ferrigno & Jobbins 1968; Portnoy 1984).

Prior to the intensive program of estuarine research carried out over the past few decades, poor management choices were the result of a general ignorance of the societal benefits of naturally functioning coastal systems. For example, the value of coastal salt marshes for pollution control, storm surge protection and the production of fin-fish and shellfish was poorly appreciated before 1970. The impacts of ecologically inappropriate management actions, undertaken without scientific assessment, have accumulated making subsequent management decisions more and more complicated and system response less and less predictable. Meanwhile, development within the coastal zone have often put facilities and structures in locations, like flood plains and barrier beaches, where they could not be protected without degrading natural coastal processes.

A more sustainable alternative to the *ad hoc* management approach is to modulate society's use of coastal resources based on detailed and site-specific ecological knowledge. This knowledge includes a scientifically derived understanding of 1) the coastal system's natural composition, development and environmental trajectory before modern human disturbance and 2) the response of the coastal system to both human-induced and natural change. With this background, resource management, like science, becomes a more informed and cumulative process in which the ultimate goal of preserving the system's functions and values to society is most predictably achieved.

This paper assembles and summarizes the ecological context for improved management of the Pamet River (Truro, Massachusetts) with emphasis on the diked, and now freshwater, portion upstream of Route 6 within Cape Cod National Seashore (Fig. 1). The river system's post-European settlement history is representative of Cape Cod's many small estuaries, as are recent assessments of alternatives for its improved long-term management.

Post-glacial Development of the Pamet

About 15,000 thousands years ago, meltwater from the South Channel Lobe of the Laurentide glacier scoured through sand and gravel outwash deposits to form the Pamet Valley (Oldale 1992). During this period, sea level was at least 100 m (several hundred feet) lower than today because of the volume of water locked in glacial ice. As the climate warmed and glaciers melted in the early Holocene, sea level rose rapidly, at a rate that prevented wetland plant colonization of the flooding river basin. Research in the Great Marsh of Barnstable, also on Cape Cod, suggests that sea-level rise slowed about 4000 years BP (before present) to a rate that was matched by sedimentation; the resulting shallow-water substrates were then colonized by emergent wetland plants (Redfield 1972).

The oldest radiocarbon dates for Pamet River sediment cores, 3500 years BP (Leatherman 1981), were similar to Redfield's (1972) data for Barnstable marshes (3400-3600 years BP). However, these Pamet peat cores collected just upstream of the present Route 6, though similar in length to Redfield's (6-8 m), did not reach the bottom of the wetland peat; thus, the onset of marsh development in the upper Pamet is uncertain.

Leatherman (1981) reported that peat color and texture indicated freshwater wetland development to within 1 m of the modern wetland surface; however, his sediment lithologies describe grey-olive clays, silts and sands from 30 cm to the core bottom at over 600 cm. Highly inorganic peats, composed of grey silts and clays, are more indicative of tidal saltwater than freshwater wetlands (Kosters et al. 1987). This would suggest that seawater and tidally imported inorganic sediment from Cape Cod Bay was reaching the upper Pamet (at least to the current Route 6 area) at about the same time as incipient wetland development. Thus, it would seem that salt marsh existed in the upper Pamet for at least 3000 years prior to European settlement.

The extent of this salt marsh upriver has been open to question (Giese & Mello 1985). Peat cores from Ballston Beach (Fig. 1) were interpreted to comprise mostly freshwater wetland peat (Leatherman (1981); however, peat blocks dislodged by an overwash at Ballston Beach in 1991 contained salt marsh grass rhizomes from about 15 cm below the surface to a depth of at least a meter (C. Roman & J. Portnoy, personal observation). Based on sediment accumulation rates from nearby Nauset Marsh (Roman et al. 1997), this peat depth suggests that tidal salt marsh extended to the eastern end of the flood plain from at least 1500 years ago to European settlement.

The seawater that regularly flooded the Pamet Valley entered from Cape Cod Bay; however, the outwash valley extended eastward all the way to the Atlantic, from which it was (and is) separated by a narrow barrier beach. With rising sea level throughout the Holocene, this barrier beach has migrated westward and has occasionally been overwashed by severe storms (Giese & Mello 1985), the most recent of which was in 1992. This potential for episodic overwash of seawater from the Atlantic has become a critical consideration for present and future management, to be discussed below.

Historical Changes to the Upper Pamet

In 1869 the upper Pamet River was profoundly changed when the Town of Truro decided to replace a bridge, located just below the present Route 6, with solid-filled Wilder's Dike (Giese & Mello 1985). The dike was fitted with a culvert and clapper valve to allow freshwater discharge while preventing seawater inflow during high tides. The wetlands upstream of the structure quickly freshened and salt-tolerant grasses (e.g. *Spartina* spp.) were replaced by salt-intolerant vegetation. Water management apparently did not change until 1952, when Route 6 was built across the flood plain just upstream of Wilder's Dike. To accommodate freshwater discharge from the upper Pamet, a four-foot culvert was installed under the new highway. There is historical evidence that the culvert was inadequate, water was impounded by the new highway and water levels rose in the diked floodplain. The only commercial cranberry bog in Truro at the time, located just north of North Pamet Road, was forced to cease operations in part because of excessively high water and sustained soil waterlogging (National Park Service 1994).

Recent analysis of shallow sediment cores from the upper Pamet corroborates these anthropogenic alterations of salinity and flooding depth (Portnoy & Giblin 1997a) (Fig. 2), as well as subsequent biogeochemical repercussions that likely degraded water quality. Cores were collected just upstream of Route 6 and analyzed for plant remains, organic content and chemical composition including stable isotopes of organic carbon. The identification of plant roots and rhizomes (Niering et al. 1977) and the isotopic ratio of carbon in sedimentary organic matter (Chmura & Aharon 1995) are powerful tools for discriminating salt marsh from freshwater wetland peat. Organic content and chemical composition can be compared to peat from both natural salt marshes and altered marshes where histories of water management are known. Thus, strong inferences about past alterations and their ecological impacts can be made from observed differences in peat composition among marshes.

The sediment record shows stable carbon isotopic ratios and rhizome remains indicative of salt marsh grasses from 60 to 20 cm depth (Fig. 2). Organic content (percent dry weight) is high, similar to that of unaltered salt marshes, at 60 cm, but much reduced at mid-depths, 55 to 15 cm. This latter depth range likely represents the vertical extent of peat drainage caused by the original 1870 diking and subsequent drainage ditches (Cortell and Associates 1983). The blockage of tidal flow, even without subsequent ditch drainage, can lower average water levels in salt marsh peat over a meter, i.e. from the elevation of mean high tide to that of discharging groundwater. Furthermore, salt marsh diking causes wetland subsidence through dewatering and pore-space collapse, loss of organic matter, and the blockage of tidally imported sediment (Thom 1992, Portnoy 1999). Organic content is lowered by aeration which increases the rate of organic decomposition. In addition, the long-term drainage and oxidation of salt marsh peat leads to serious water quality problems (Soukup & Portnoy 1986, Portnoy 1991) that, although undocumented, may have persisted for decades in the upper Pamet stressing aquatic animals.

At about 15 cm depth, the sediment composition abruptly changes to a much higher organic content and very low carbon isotopic ratio typical of freshwater wetlands. Increased organic content is expected because diking blocks the marine supply of inorganic particles normally transported to unaltered salt marshes by high-velocity flood tides (Pinigree & Griffiths 1979). However, for organic matter to accumulate, the sediment must remain waterlogged and anaerobic for much of the year to reduce the rate of organic decomposition. As mentioned, there is an historical report of freshwater impoundment in the flood plain upstream of Route 6 after 1952 (National Park Service 1994); this report seems to explain the fairly recent switch, evident in the sediment record, from apparently drained salt marsh to waterlogged freshwater wetland. The re-saturation of previously drained peat likely re-established chemically reducing conditions and improved conditions for the freshwater organisms which had invaded the once-saline flood plain.

The barrier beach at Ballston has overwashed three times in recent decades, in February 1978, October 1991 and December 1992 (Fig. 3). The latter two overwashes filled the diked flood plain with seawater to a depth of 60 cm (2 ft). The large volume of overwashed water could only exit the system through the small culvert under Route 6, and only during low tides because of the clapper valve. Consequently, saline water remained on the wetland surface for nearly 2 weeks. Porewater monitoring in the root zone of the plant community showed that brackish conditions persisted for about three months in plant communities closest to the river channel (i.e. 100 m from the upland edge, Fig. 4). Of course, salt marsh vegetation in unaltered marshes is tolerant of overwashed seawater and may even benefit from overwashed sand which helps the marsh keep up with sea-level rise. The upper Pamet River wetlands are, however, not salt-tolerant and extensive mortality was only averted because plants were dormant.

Coincidentally, seawater has re-entered other diked portions of the lower Pamet River system, west of Route 6, in unplanned and episodic fashion recently. During the late 1980's, storm tides eroded the railroad grade at Mill Pond and Eagle Neck Creek. Unlike the overwash at Ballston Beach, these breaches remained open allowing regular salt water flooding of wetlands that had been isolated from the tides for 120 years. A well-developed community of freshwater wetland shrubs and herbs were killed, leaving large areas of unvegetated mudflat. Many local residents complained about the plant mortality and about sulfide odors arising from the newly salinated wetland, but the town chose to leave the railroad dikes open to tidal flow. Within a year the odors, caused by renewed sulfate reduction – a natural microbial process in all salt marshes, subsided. Over the past ten years, much of the bare mudflats have been re-colonized by salt marsh grasses forming an almost continuous carpet under the stark skeletons of the salt-killed woody vegetation.

Following the two Ballston Beach overwashes of 1991and 1992, local officials realized that future overtopping events were inevitable and that impounded seawater could damage structures and roads or contaminate domestic wells within the upper Pamet River flood plain. Therefore, the Town of Truro and Cape Cod National Seashore funded a study, conducted by the US Army Corps of Engineers and the Cape Cod Commission, to assess the alternatives for managing the upper Pamet to accommodate future overwashes (Kedzierski et al. 1998). Land managers were particularly interested in the potential for partial tidal restoration as a way of recovering lost natural resource values while providing for the rapid discharge of overwashed water along the natural gradient toward Cape Cod Bay. National Seashore managers and others recognized that overwashes in the recent past (since 1978) had produced little change only because they had occurred during the dormant season. Seawater flooding during the summer, on the other hand, would likely cause rapid and extensive mortality of plants and aquatic fauna, and long-term effects on water quality, plant ecology and biogeochemical cycling.

The Corps conducted field surveys of topography and tidal forcing to develop a hydrologic model of the Pamet, in part based on earlier work (Lewis 1989, Giese et al. 1990). The Corps study determined that enlarged culverts (6 ft by 16 ft) at Route 6 and Wilder's Dike could provide sufficient cross-sectional area to allow overwashed water to exit the upper Pamet in less than two days. These culverts, if built without tide gates, would also allow enough regular seawater flooding to cause salt marsh restoration through much, but not all, of the upper Pamet. The highest salinity wetlands would occur just above Route 6, grading into brackish and then freshwater wetlands as salinity decreased along an eastward gradient.

As part of the Corps study, Cape Cod Commission hydrologists determined that the thickness of the freshwater lens in the Pamet Valley (more than 120 ft) and the wetland peats surrounding the river precluded any impacts of salt water flooding on domestic wells, even if maximum estimated tidal flow from Cape Cod Bay were restored. This analysis further found that groundwater levels 500 ft or more from the river should not be affected by the introduction of anticipated tidal flows in the river (Eichner et al. 1997).

By the time the Corps and Commission report was finalized (April 1998), however, the impressive overwashes of 1991 and 1992 were largely forgotten. The barrier dune at Ballston Beach had shifted back from the ocean and recovered its height to again pose a major barrier to storm overwash. The Corps's recommendations for long-term management of inevitable future overwashes, along with the benefits of salt marsh restoration in the upper Pamet, were apparently largely ignored. Nevertheless, the upper Pamet remains vulnerable to severe ecological disturbance in its presently diked condition.

Current Conditions

The 65-ha (160-acre) upper Pamet River basin is presently dominated by freshwater wetland vegetation including both herbaceous and woody species. Although no quantitative data are available, casual inspection of aerial photographs (1938, 1947, 1960 and 1987) indicates an extensive shift from wetland grasses and open water to trees and shrubs. This trend is typical for tidally restricted coastal marshes Cape-wide (Portnoy & Soukup 1982). Effects of the 1978, 1991 and 1992 overwashes are evident only in the new sand deposits and some shrub mortality just inland (west) of Ballston Beach.

As mentioned, historic tidal restrictions and ditch drainage led to sediment compaction and subsidence so that the wetland surface is now about 60 cm (2 feet) below that of unaltered salt marsh downstream of Wilder's Dike (Giese et al. 1990)

Water quality evidently supports a diverse freshwater fauna (Marine Research Inc. 1986). Despite the isolation of sulfur-rich salt marsh soils well beyond the reach of the tide, freshwater impoundment by Route 6 since its construction in 1952 has kept the soils anaerobic and the sulfur stable (chemically reduced) in the solid phase. Thus, unlike conditions in other diked outer Cape wetlands, like Herring River in Wellfleet (Portnoy & Reynolds 1997) and Salt Meadow in North Truro, acid sulfate soil generation and surface water acidification are presently not problems in the Pamet system. However, the buried peat deposits comprise a huge reserve of sulfur, iron, nitrogen, phosphorus and organic carbon, all of which can be mobilized by changes in the wetland's flooding regime to affect the quality of receiving waters (Portnoy & Giblin 1997b).

Looking Forward: Considerations for Future Management

Cape Cod's fresh ground water rests on seawater and necessarily rises along with sea level; therefore, the diked Pamet marsh continues to rise along with ground water levels, but in a way that, importantly, is very different from the way a salt marsh grows. Salt marshes have kept pace with sea-level rise largely through the accumulation of inorganic sediment, i.e. sand, silt, & clay (Pinigree & Griffiths 1979). The diked upper Pamet has been denied this sediment supply for over a hundred years. In the meantime, any accretion (i.e. growth upward) has been through the production of organic matter (Fig. 2). This would be fine (and the wetland itself is very beautiful) except for two consequences of future overwashes:

1) Overwashed sea water will flood the basin for weeks, as in 1991, because the wetland surface is still well below mean high tide and because the small culvert under Route 6 impedes drainage toward Cape Cod Bay. If seawater overwashes during the warm growing season, e.g. during an Atlantic hurricane, vegetation and aquatic biota will be killed and water quality degraded;

2) Seawater will cause the organic matter that has accumulated in the freshwater Pamet to decompose rapidly, resulting in additional marsh subsidence and worsened flooding Portnoy & Giblin 1997b). Again, massive plant death and decomposition will deplete oxygen and kill fish.

The vegetation that would result from episodic, uncontrolled seawater intrusion and long periods of flooding is not easy to predict; however, it will not be as diverse as today. Open water or invasive common reed (*Phragmites australis*), which already has a foothold in the valley, may replace the present freshwater wetland community. *Phragmites* has become an aggressive invader of disturbed wetland sites throughout the Northeast U.S. (Marks et al. 1994).

If salt water were intentionally restored to the system, freshwater plants would still die to be replaced by salt tolerant species; however, the rate of plant mortality and replacement could be controlled by small, incremental increases in tidal flow. [This approach is being applied successfully at Hatches Harbor in Provincetown where a step-wise return of tidal flow has caused neither extensive plant mortality nor water quality problems; presently wide-spread *Phragmites* at Hatches is expected to decline with sustained high salinity.] Of course, an immediate advantage of installing large culverts for the Pamet at this juncture is to allow future storm-overwashed water to rapidly drain from the marsh surface at low tide. In this way, soil waterlogging and any flooding threats to structures, however remote, would be minimized.

It's very important in this context to realize the potential value of the overwash at Ballston Beach in importing sediment to rebuild the subsided and "drowning" upper Pamet marsh. Reopening the system to tidal flow from Cape Cod Bay would provide a more regular supply of sediment and a more manageable arrangement to restore equilibrium between present sea level and wetland elevations in the upper Pamet. In general, the removal of artificial tidal restrictions removes the fetters on a wetland's natural ability to resist drowning by the rising sea.

Although the upper Pamet seems beautiful and vigorous as a freshwater system, and past storm events seem to be largely forgotten, the potential persists for serious disturbance of both ecological and social values in the flood plain. Indeed, the probability of overwashes should only increase over time with the projected effects of global climate change on storm frequency and intensity (National Research Council 1983). As a first step toward informed and proactive long-term resource management, managers should publicly review and discuss the recent findings and recommendations of the many locally funded studies summarized here. These investigations used the most current scientific information on wetland functions, values and worldwide management experience to focus on and interpret the Pamet River's unique developmental history, ecological status and alternative futures. The science shows that long-term management should include plans and physical preparations to manage storm overwash from the Atlantic. Discussions should logically include the restoration of native salt marsh and estuarine habitats throughout the Pamet ecosystem.

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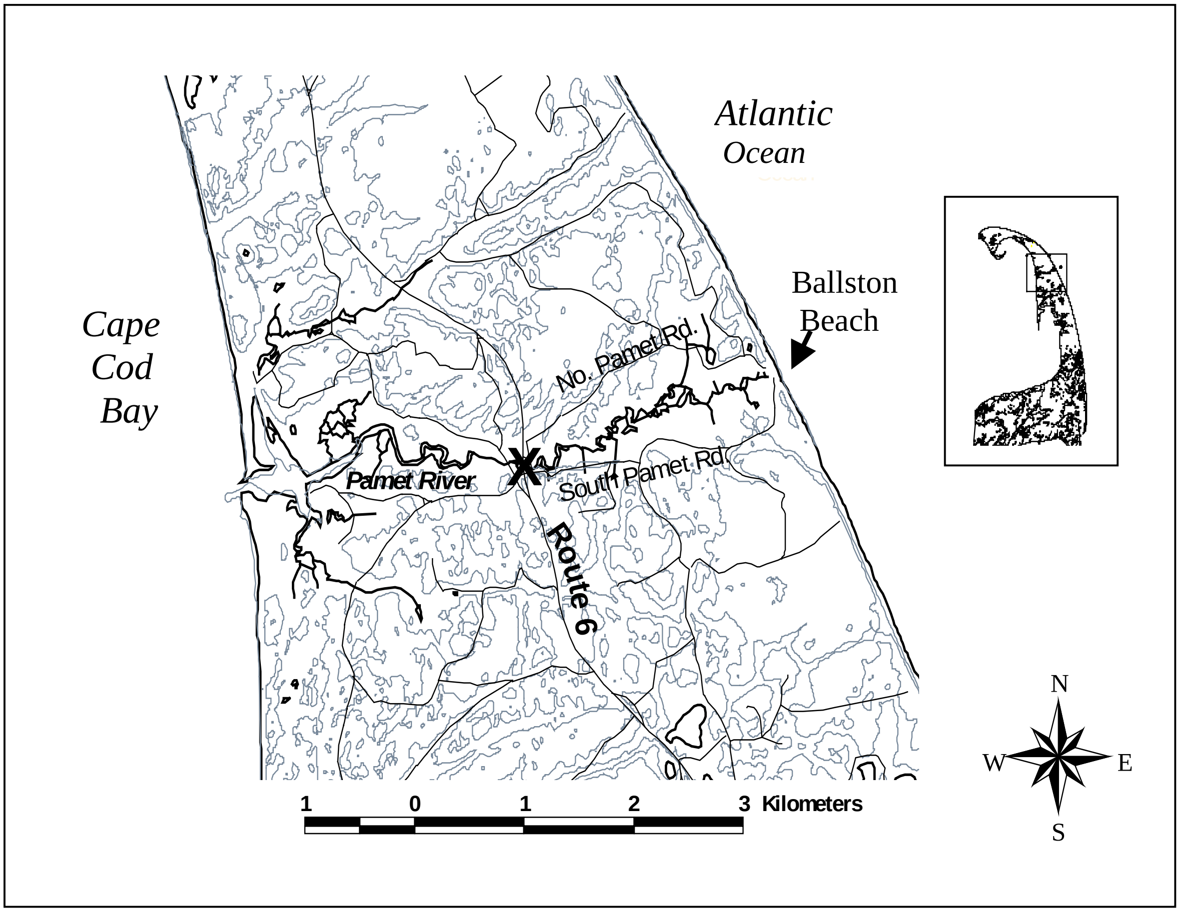

Figure 1. Pamet River (Truro) showing tidal restrictions at “X” preventing seawater flow and impounding fresh water to the east. The natural inlet is at Cape Cod Bay at the western extremity of the system. Storm surges have overwashed the barrier dune system at Ballston Beach.

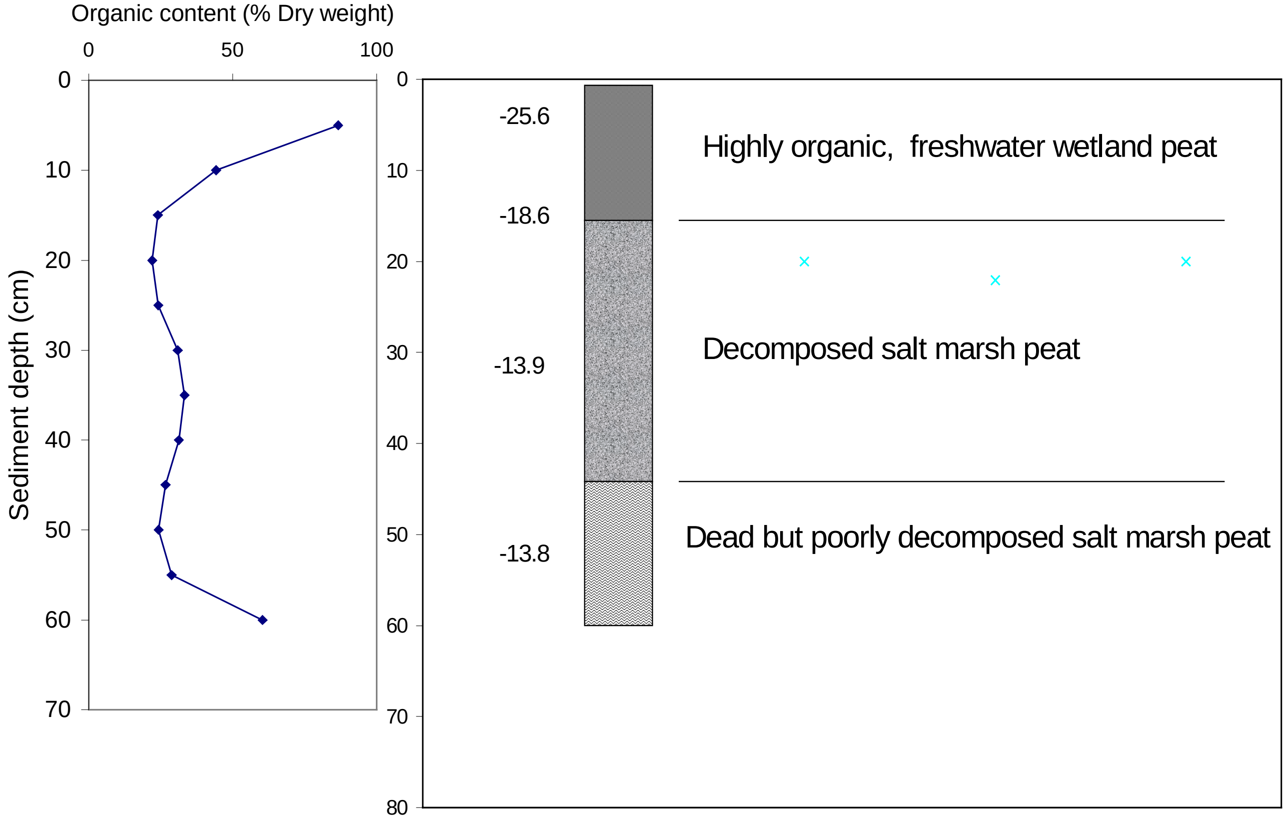

Figure 2. Peat core from Pamet River wetlands just east of Route 6. Negative numbers to the left of the core profile are stable carbon isotopic ratios (delta C-13 values) indicating the vegetative community, and thus salinity regime, at the time of sediment deposition. Lowest values at the surface indicate freshwater wetland and terrestrial sources of organic carbon. Higher values further down-core are typical of salt marsh grasses. Decomposed and compacted salt marsh peat between 15 and 45 cm suggests a period of intensive drainage and aeration after diking. Highly organic freshwater peat at the surface probably accumulated since Route 6 construction in 1952, which impounded freshwater on the previously drained salt marsh surface.

Figure 3. Overwash at Ballston Beach, Truro during the "Perfect Storm" of 31 October 1991. The storm surge breached the barrier dune (top) and forced seawater onto the flood plain to a depth of several feet (bottom). Tidal restrictions since 1869 have converted the upper Pamet plant community from salt marsh to salt-intolerant wetland species. After the overwash, seawater persisted for over a week in the river proper, and for months in the sediment. Extensive mortality of current freshwater-wetland vegetation was averted only because plants were dormant.

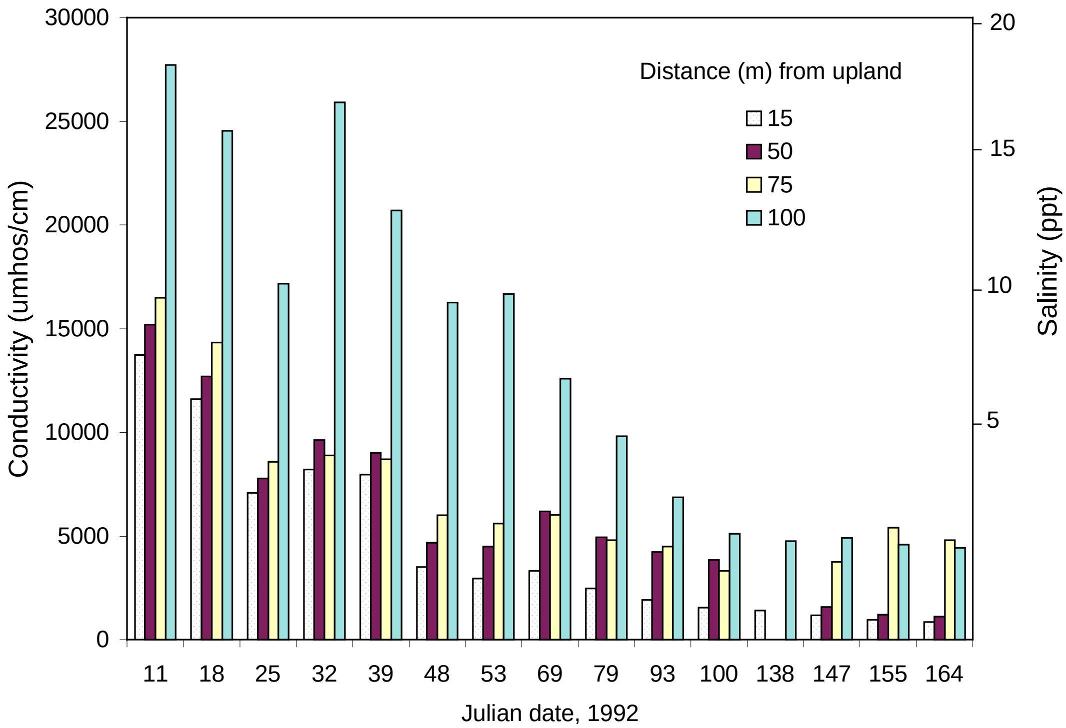

Figure 4. Conductivity and salinity of wetland porewater in the upper Pamet River after flooding with seawater in early January 1992. Data are presented for four stations at 15-100 m from the upland border.